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June 24, 2003
L-03-103

U. S. Nuclear Regulatory Commission
Attention: Document Control Desk
Washington, DC 20555-0001

Subject: Beaver Valley Power Station, Unit No. 1
BV-1 Docket No. 50-334, License No. DPR-66
Reactor Head Inspection 60-Day Report

Reference:
1) NRC Order (EA-03-009) Establishing Interim Inspection Requirements for Reactor Pressure Vessel Heads at Pressurized Water Reactors, dated February 11, 2003

During the recent BVPS Unit 1 1R15 Refueling Outage, inspections of the reactor pressure vessel (RPV) head and associated penetration nozzles were performed. In accordance with NRC Order EA-03-009 (Reference 1) Section IV.E, the 60-day report, detailing the inspection results is being provided. The BVPS Unit 1 1R15 report is enclosed with this letter.

There are no new regulatory commitments contained in this letter. If there are any questions concerning this matter, please contact Mr. Larry R. Freeland, Manager, Regulatory Affairs/Performance Improvement at 724-682-5284.

Sincerely,

L. W. Pearce

L. William Pearce

Enclosure

c: Mr. T. G. Colburn, NRR Senior Project Manager
Mr. D. M. Kern, NRC Sr. Resident Inspector
Mr. H. J. Miller, NRC Region I Administrator

FirstEnergy Nuclear Operating Company (FENOC)

Evaluation Report for 1R15

Visual and Under-head Inspection

of

Beaver Valley Unit 1

Reactor Vessel Head Penetrations

(Ref: Order EA-03-009)

Evaluation Performed by Eric Loehlein

Evaluation Reviewed by Dennis Weakland

June 2003

Introduction

Reactor Pressure Vessel (RPV) Head Inspections were performed at Beaver Valley Power Station (BVPS) Unit 1 during the 1R15 Refueling Outage in accordance with NRC Order EA-03-009. The Order establishes criteria by which licensees must perform periodic inspections of the reactor vessel head. FirstEnergy Nuclear Operating Company (FENOC) provided a response to the Order for BVPS via letter L-03-035 dated March 3, 2003. A Relaxation Request to the Order for BVPS Unit 1was filed on March 27, 2003 (letter L-03-053, and supplemented by letter L-03-057 dated April 2, 2003). To account for limitations in the current industry accepted inspection technology, it was requested that ultrasonic and eddy current inspection coverage of the Control Rod Drive Mechanism (CRDM) tubing extend to "the lowest elevation that can be practically inspected on each nozzle with the probe being used". Written approval from the NRC of this relaxation was received on April 18, 2003, stipulating that "examination coverage from the bottom of the J-groove weld shall be at least 1 inch". The approval was contingent upon further licensee action should the NRC find the crack growth formula in industry report MRP-55 unacceptable.

Purpose and Scope

The purpose of the inspections performed was 1) to identify any evidence of leakage from the CRDM penetrations or Head Vent piping penetration onto the surface of the RPV head, and 2) to identify any relevant indications in the J-groove welds or RPV head penetration base material.

The susceptibility of the Beaver Valley Unit 1 RPV head to PWSCC-related degradation was calculated using the formula provided in Section IV(A) of the Order. Using best estimate values for each parameter, the Unit 1 RPV head susceptibility was calculated to be 13.84 Effective Degradation Years (EDY) at the conclusion of Operating Cycle 15. This value places the Unit 1 RPV head at greater than 12 EDY, the "High Susceptibility" category as outlined in the Order.

The required inspection techniques for High Susceptibility plants to be completed each refueling outage are outlined in Sections IV(C)(1)(a) and (b) of the Order, namely:

(a) Bare metal visual examination of 100% of the RPV head surface (including 360° around each RPV head penetration nozzle), AND

(b) Either:
   (i) Ultrasonic testing of each RPV head penetration nozzle (i.e., nozzle base material) from two (2) inches above the J-groove weld to the bottom of the nozzle and an assessment to determine if leakage has occurred into the interference fit zone, OR
   (ii) Eddy current testing or dye penetrant testing of the wetted surface of each J-Groove weld and RPV head penetration nozzle base material to at least two (2) inches above the J-Groove weld.

Qualified contractor personnel using high-resolution remote visual inspection equipment performed visual inspection of the top of the RPV head. Qualified contractor personnel with BVPS Site Non-Destructive Examination (NDE) personnel providing concurrence performed VT-2 inspection of the RPV head penetrations and base metal. Qualified visual examination was completed on 360° around each CRDM penetration and the Head Vent, as well as a complete assessment of the carbon steel base metal inside the ventilation shroud where the RPV head penetrations are located.

The nondestructive examinations performed were conducted in accordance with site-specific field service procedures. With the exception of the vent line examination procedures, all have been demonstrated through the Electric Power Research Institute / Materials Reliability Program (EPRI/MRP) protocol. In the absence of an EPRI/MRP protocol for the vent line applications, the examination procedures and techniques followed the basic requirement outlined in ASME B&PVC (edition 2000) Sec. XI, Appendix IV, Supplement 2 - "Qualification Requirements for Surface Examination of Piping and Vessels". The technique used is further outlined in Westinghouse Technical Justification WDI-TJ-011-03.

Under-head inspections of the RPV head penetration base material and J-groove welds were performed by qualified Level II/III NDE personnel. A NDE examiner from EPRI provided independent review of the data.

The preceding inspections satisfy Order EA-03-009 requirements for BVPS Unit 1. This included eddy current examinations performed on the wetted surface of all RPV head penetration J-groove welds, the penetration tube IDs (from at least 2 inches above the J-groove weld to at least 1 inch below the J-groove weld), and the penetration tube ODs (from the bottom of the weld to the lowest extent possible, to a minimum of at least 1 inch).

In addition, ultrasonic examination was performed on 27 of 65 penetrations from at least 2 inches above the weld to within 1 inch of the bottom of the nozzle. RPV head configuration issues prohibited ultrasonic inspection on most outer penetrations.

Inspection Results: Visual Inspection of the RPV Head Surface

VT-2 visual inspection of 360° around each of the 65 CRDM penetrations and the vent line showed no indication of penetration leakage characteristic of a through-wall leak. Figure 1 shows the typical condition found around each penetration during the penetration exam.

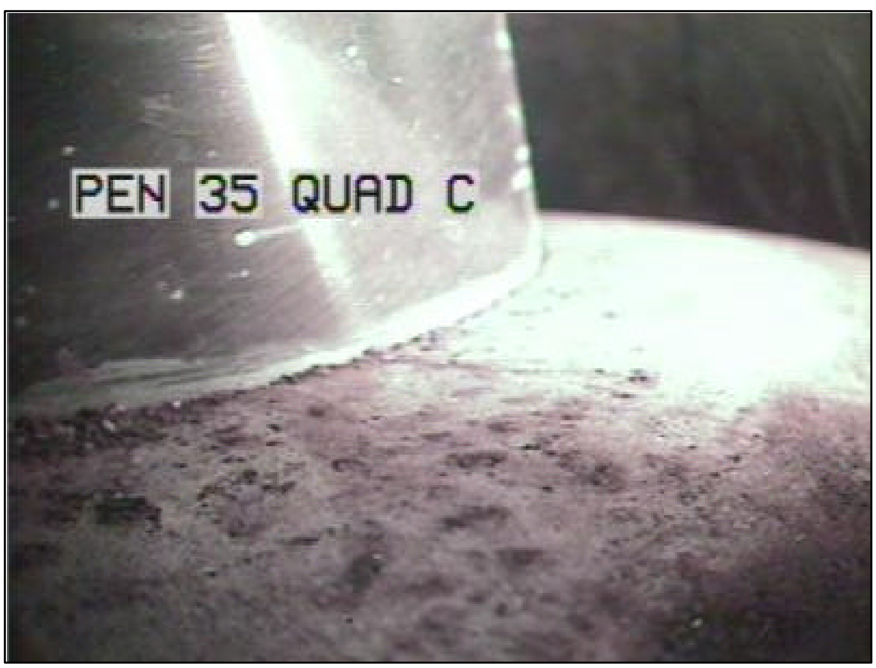


Figure 1: Typical 1R15 CRDM Penetration Condition

The carbon steel assessment performed on 100% of the RPV head carbon steel base metal inside the ventilation shroud found no new degraded conditions on the RPV head surface. Figure 2 shows the typical condition of the RPV head base metal.

Figure 2: Typical 1R15 Carbon Steel Condition

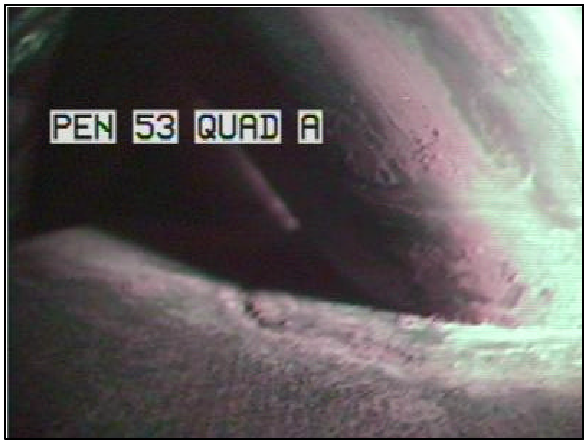
Minor corrosion of the RPV head base metal was observed around CRDM Penetrations 53 and 65. This condition was previously observed in the visual inspection performed during the 1MO2 Maintenance Outage in November 2002 and in the 1R14 refueling outage in 2001 (Penetration #65). The leakage that caused the degradation was determined to have originated at the adjacent canopy seal (Penetration #53) above the RPV head mirror insulation. Following a warm water rinse of the RPV head in 1MO2, the extent of the degradation was assessed. This documentation was reviewed with the NRC BVPS site resident inspector in November.

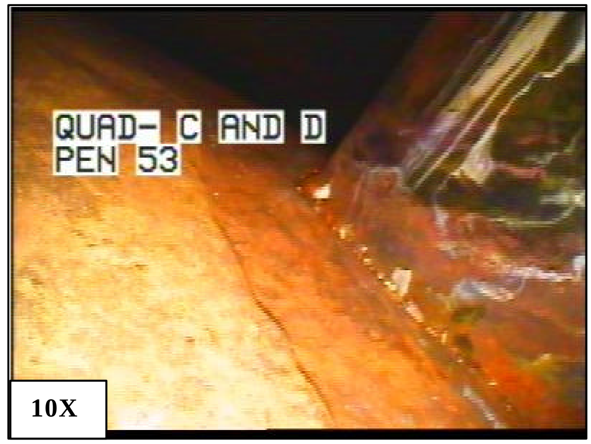
The conditions of Penetrations 53 and 65 observed during the 1R15 refueling outage were compared with the previously documented conditions. No change in the condition of the RPV head base metal around Penetrations 53 and 65 was observed. Figures 3 through 6 show the conditions documented during 1R15.

Evaluation of Results: Visual Inspection

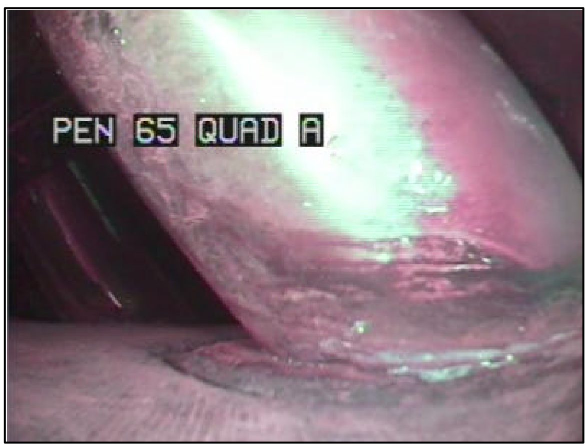
No evidence of RPV head penetration leakage was observed. Additionally, the under-head examination performed during 1R15 further confirmed that no through-wall flaw was present in any RPV head penetrations or J-groove welds.

The minor corrosion observed around Penetrations 53 and 65, previously evaluated during 1MO2 in November 2002 and reviewed with the NRC BVPS site resident inspector, was found to be approximately 1/8” in depth and 1/2” wide around the perimeter of the two CRDM penetrations. This degradation was concluded to be minor in nature and well within the acceptable limits for the BVPS Unit 1 RPV Head. As no change in conditions was observed during 1R15, this assessment remains valid.





Figures 3 and 4: Penetration 53



Figures 5 and 6: Penetration 65

Inspection Results: Under-head Inspection (BV Condition Report # 03-03756)

Eddy current wetted surface examination of all 65 CRDM penetration J-groove welds found no indications characteristic of cracking in any of the welds. Eddy current inspection was also performed on the vent line J-groove weld using a 12-channel probe-array. This exam also found no indication of degradation.

Eddy current wetted surface examination was performed on the OD surface of all 65 CRDM penetrations. Reportable indications, with characteristics of Primary Water Stress Corrosion Cracking (PWSCC), were identified in the penetration tube scans of four CRDM locations. Penetrations #50, 51, 52, and 53 contained indications initially classified as having crack-like characteristics; single axial indications (SAI), single circumferential indications (SCI) and/or multiple circumferential indications (MCI). Following Time of Flight Diffraction (TOFD) Ultrasonic analysis of the four penetrations from the ID surface, all indications were ultimately classified as axial in orientation. Neither eddy current nor ultrasonic test results identified any crack extension into the J-groove weld.

There were no indications characteristic of cracking identified in any of the remaining 61 CRDM penetration OD surface eddy current exams.

Eddy current wetted surface examination was also performed on the ID surface of all 65 CRDM penetrations as well as the vent line. Results from the tube ID eddy current surface scans identified nine penetration tubes (#8, 9, 12, 36, 47, 49, 51, 52, 53) with indications characteristic of craze cracking. The craze cracking was not detectable with the TOFD ultrasonic probes, indicating the depths of the condition are less than 0.040", the TOFD probe detection limit. As such, they are not considered to have any impact on the integrity of the RPV head penetration tubes, per the flaw evaluation guidance provided in the letter from J. Strosnider, NRC, to A. Marion, the Nuclear Energy Institute (NEI), dated November 21, 2001.

Eddy current ID surface examination of the remaining 56 CRDM penetrations, as well as, eddy current examination of the reactor vessel head vent line, found no reportable indications.

TOFD ultrasonic examination was performed on 27 CRDM penetrations (the four penetrations having OD indications identified through OD eddy current surface examination, as well as 23 other penetration tubes) and the reactor vessel head vent line. The TOFD ultrasonic examinations performed on Penetrations #50, 51, 52, and 53 were used to characterize the OD indications identified during the eddy current wetted surface exam. The indications were found to vary in depth between 0.060" and 0.300". The length of the indications varied between 0.25" and 1.6". Ultrasonic examinations performed on the other 23 CRDM penetrations identified no reportable indications.

Evaluation of Results: Under-head Inspection

The details of the relevant indications found on Penetrations #50, 51, 52, and 53 are provided in the attached figures and tables. Figure 7 shows the typical location of each flaw axially on the penetration. Tables 1 through 4 describe the approximate length, depth, disposition, and circumferential location of each indication. Figures 8, 10, 12, and 14 show the tube profile and each indication extending up to the toe of the J-groove weld. Figures 9, 11, 13, and 15 show a top-view of each penetration and approximate location of the indications discovered.

Each of the four penetration tubes that exhibited OD cracking was manufactured from the same heat of Alloy 600. This heat, M3935, made by B&W Tubular Products Division, was procured to the requirements of ASME SB-167 as supplemented by Article 3, Section III of the ASME Boiler and Pressure Vessel Code. A comparison of the certified materials test report and the ASME requirements indicates the material meets all chemistry and mechanical property requirements.

Nevertheless, reactor vessel head penetrations of this heat of material have been reported as cracked in several other domestic plants. In each case, the environmental degradation mechanism has been identified as primary water stress corrosion cracking (PWSCC).

The susceptibility to PWSCC is a function of the specific material characteristics (microstructure, carbide distribution, etc.), the effective stress, and the service temperature. For austenitic nickel-base alloys such as Alloy 600, PWSCC is a thermally activated process; the initiation rate can be described by Equation 1:

$$\frac{1}{t} = Rate = A\sigma^n e^{-Q/RT} \qquad \text{Equation 1}$$

where:

- A is a term that describes the microstructural and other material conditions of the material;
- σ is the effective stress term (resulting from applied and residual stresses)
- n is the stress exponent; a value of 4 is used for PWSCC
- Q is the activation energy for the crack initiation process; a value of 50 kcal/mole is commonly used for Alloy 600; this same value has been used in the EPRI MRP reports on Alloy 600
- R is the gas constant (1.987 cal/mole K)
- T is the absolute temperature in K, and
- t is the time to initiate cracking

While the specific factors contributing to the apparently low resistance to PWSCC of heat M3935 have not been established, it is judged to most likely be the result of a marginal microstructure combined with high residual stresses. Of the four heats of Alloy 600 represented in the Beaver Valley Unit 1 head penetrations, heat M3935 has the highest reported yield strength. A summary of these values is presented in the following table:

Heat	**No. of Penetrations**	**Material Mfgr.**	**Yield Strength, ksi**
M3935	4	B&W	48.4
C2649	55	B&W	35.9
M2065	5	B&W	43.2
NX9420	1	Huntington Alloys	39.0

Note that all four of the penetrations made with heat M3935 were found to exhibit degradation.

Equation 1 indicates that the time-to-crack-initiation varies inversely with the fourth power of stress. The net effective stress includes contributions due to residual, operating, and/or thermal stresses. Other conditions remaining constant, higher yield strength material is likely to maintain higher residual stresses from fabrication and, hence, may be prone to cracking in a shorter period of time. In most cases, local (residual) stresses introduced by cold work and welding during fabrication are more important than service stresses since service stresses are generally well below the yield stress. Component fabrication processes such as welding, rolling, reaming, bending and cold work will introduce residual stresses in the material that may contribute to PWSCC.

A common practice with B&W penetrations was the use of rotary straightening following all primary fabrication of the pipes. This process is known to induce high residual stresses on the OD surface and would tend to further exacerbate the residual stresses introduced by welding and other manufacturing processes. This is judged to be a major reason why degradation of this heat of Alloy 600, and other B&W Alloy 600 heats, has occurred predominantly on the OD surface.

Remedial Actions

Repairs were performed on Penetrations 50 through 53 using the Embedded Flaw Repair Technique, consisting of a three-pass Alloy-52 weld overlay of the J-groove weld and a two-pass overlay of the penetration tube OD for each of the four penetrations. Verbal NRC approval of BVPS Relief Request BV3-RV-04 for the use of this technique was received on April 18, 2003, followed by written approval from the NRC on May 14, 2003. Post-repair dye penetrant examinations of all repaired regions were satisfactory.

Upon completion of the repairs Ultrasonic and Eddy Current examinations were performed to verify that that repair process did not introduce any new flaws or adversely change the size of characteristics of the previously reported flaws. Analysis of the post-repair TOFD ultrasonic examination results revealed no new indications. Furthermore, the TOFD sizing results indicate the through-wall dimensions and lengths of the reflectors did not change as a result of the repair process.

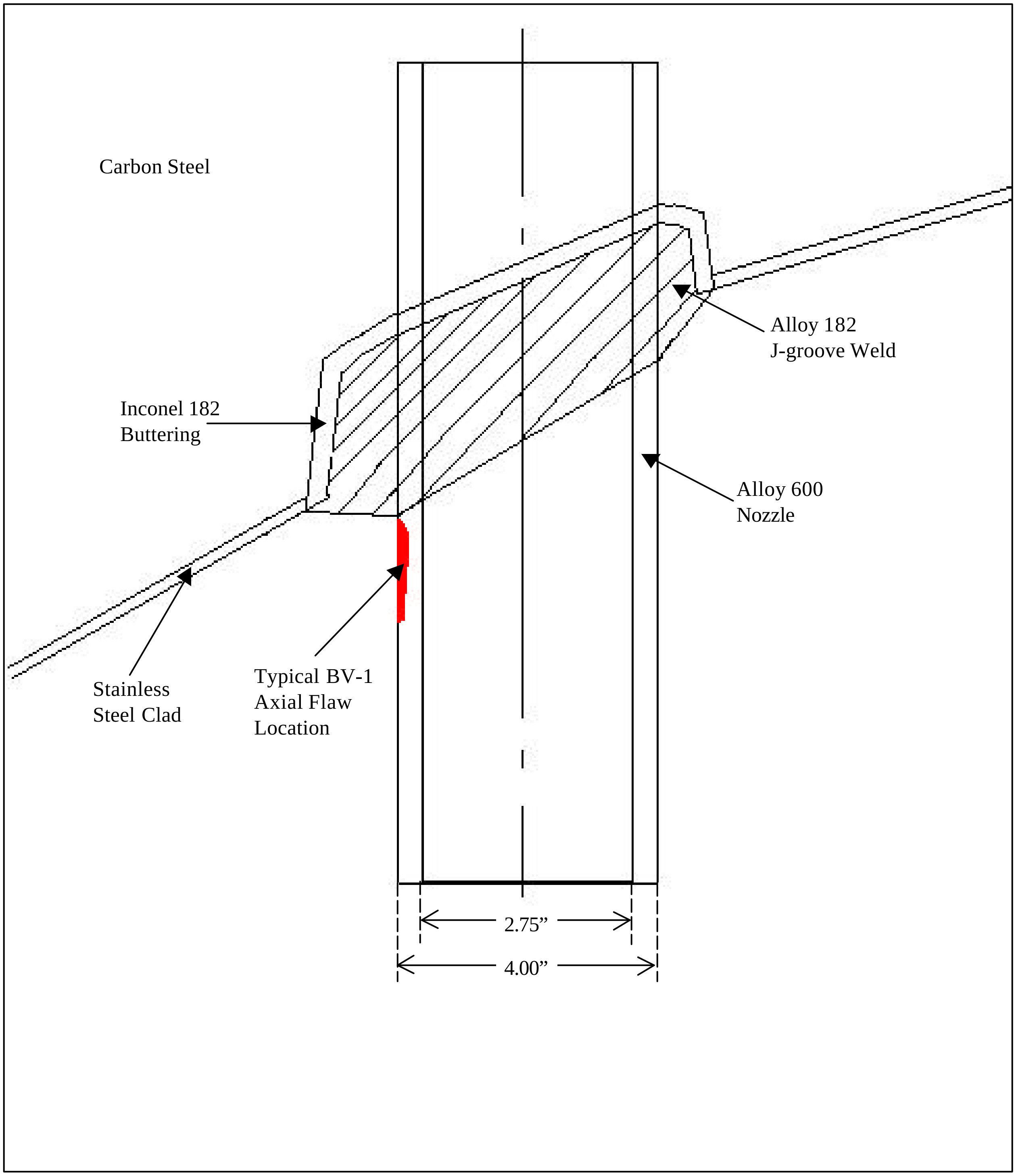
The conclusion can be made that the applied repair process had no detrimental effect on the tubes, did not result in any crack growth and did not result in the initiation of any additional cracking in the tubes.

Summary

Visual and under-head Inspections of all RPV Head Penetrations were completed in accordance with NRC Order EA-03-009 and the relaxation to the Order approved by the NRC on April 18, 2003. Visual Inspection of the RPV head surface showed no evidence of a through-wall RPV head penetration leak or undocumented RPV head degradation. Under-head eddy current and/or ultrasonic inspection of RPV head penetrations revealed relevant indications on the OD of four CRDM penetrations. None of the indications were through-wall, nor did analysis show them to extend into the pressure boundary region of the tube or J-groove weld.

Repairs were effected on Penetrations #50, 51, 52 and 53 using the embedded flaw repair technique per BVPS Relief Request BV3-RV-04, which was approved by the NRC. A three layer Alloy-52 weld overlay was applied to each J-groove weld, and a two-pass weld overlay was applied to the OD of each of the affected penetrations. Post-repair dye penetrant examinations of all repaired regions were satisfactory. Furthermore, post-repair eddy current and ultrasonic examination of each penetration confirmed no new flaws were created nor did the size and characteristics of the existing flaws change as a result of the repair process.

<u>Figure 7: Typical Axial Flaw Location</u>
Penetrations #50, 51, 52, and 53



Penetration #50: Flaw Characterization

Table 1: Penetration #50 Flaw Characterization

#	Length (Inches)	Depth (Inches)	Disposition	Circ. Location
1	1.25”	0.30”	Single Axial	97°
2*	~0.8”	<0.125”	Multiple Shallow Axial	90°-135°
3*	1.55”-1.80”	<0.125”	Multiple Shallow Axial	230°-320°

*Length dimension indicates range of affected area not the length of individual flaws.

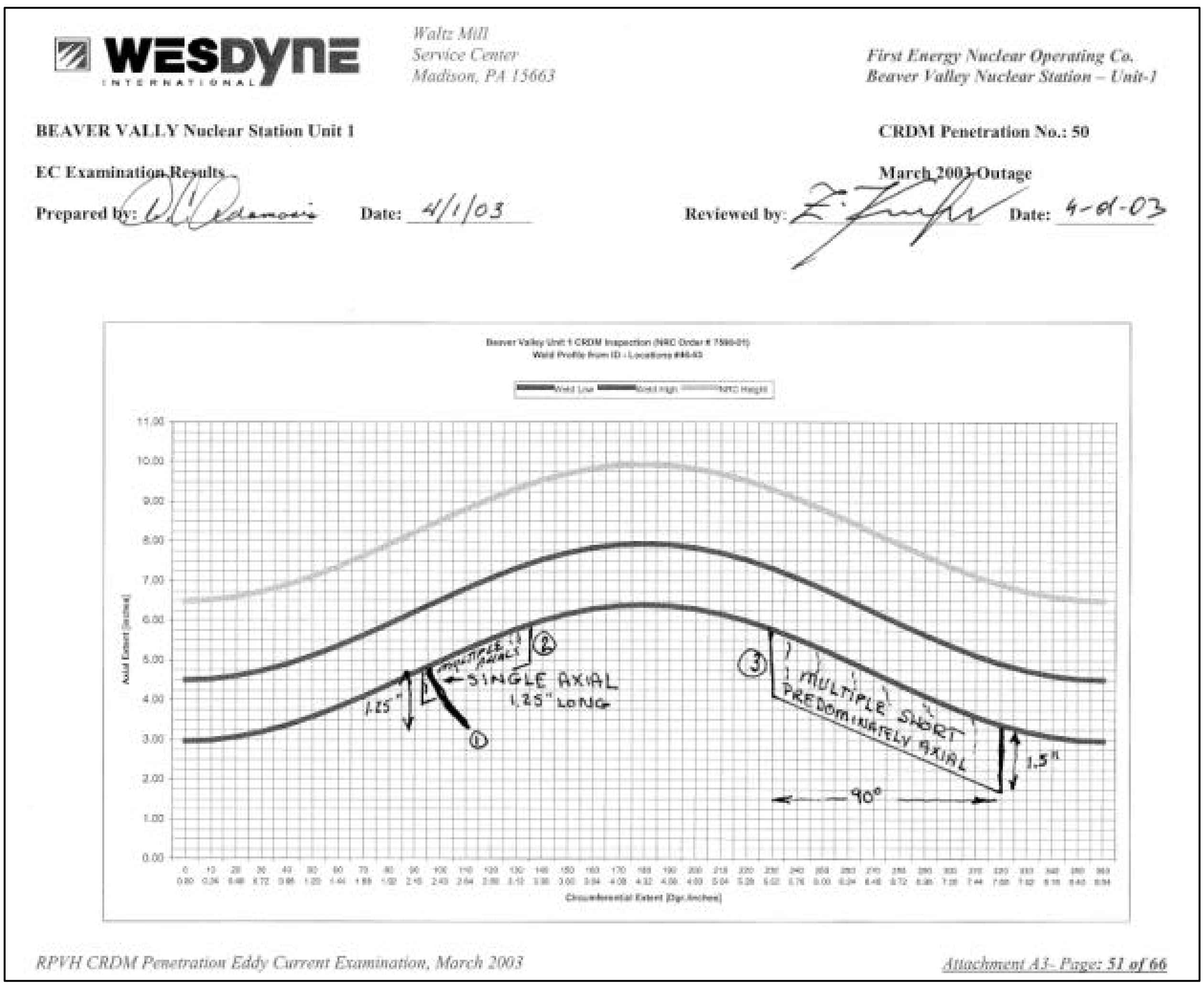


Figure 8: CRDM Penetration #50 Tube Profile

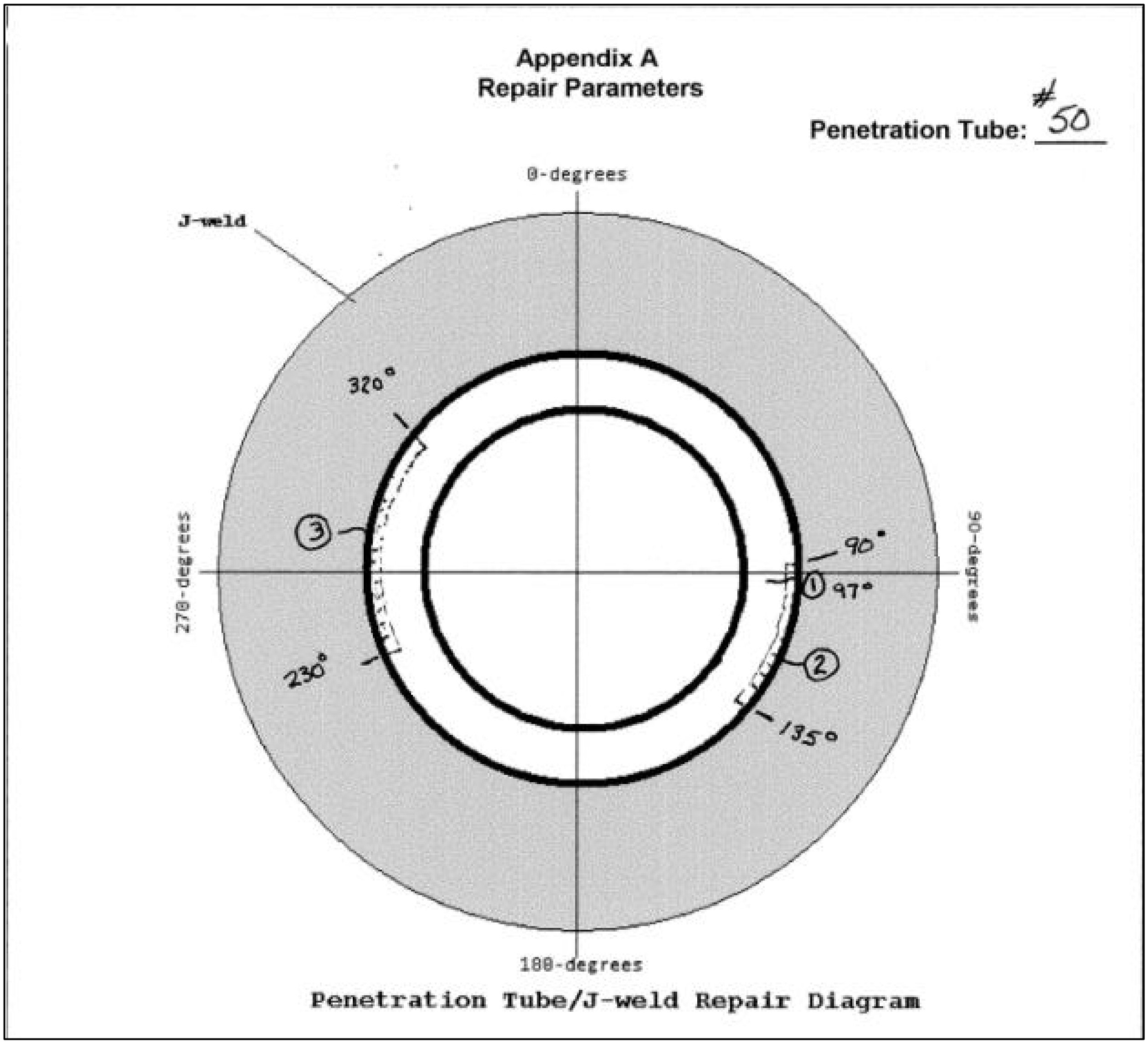


Figure 9: CRDM Penetration #50 Repair Parameters

Penetration #51: Flaw Characterization

Table 2: Penetration #51 Flaw Characterization

#	Length (Inches)	Depth (Inches)	Disposition	Circ. Location
1	1.0”	0.25”	Single Axial	37°
2	1.6”	0.25”	Single Axial	67°
3	0.6”	0.25”	Single Axial	80°
4	0.8”	0.25”	Single Axial	90°
5	0.85”	0.25”	Single Axial	110°
6	0.35”	0.25”	Single Axial	182°
7	0.25”	0.25”	Single Axial	270°
8	0.3”	0.20”	Single Axial	280°
9	0.3”	0.20”	Single Axial	290°

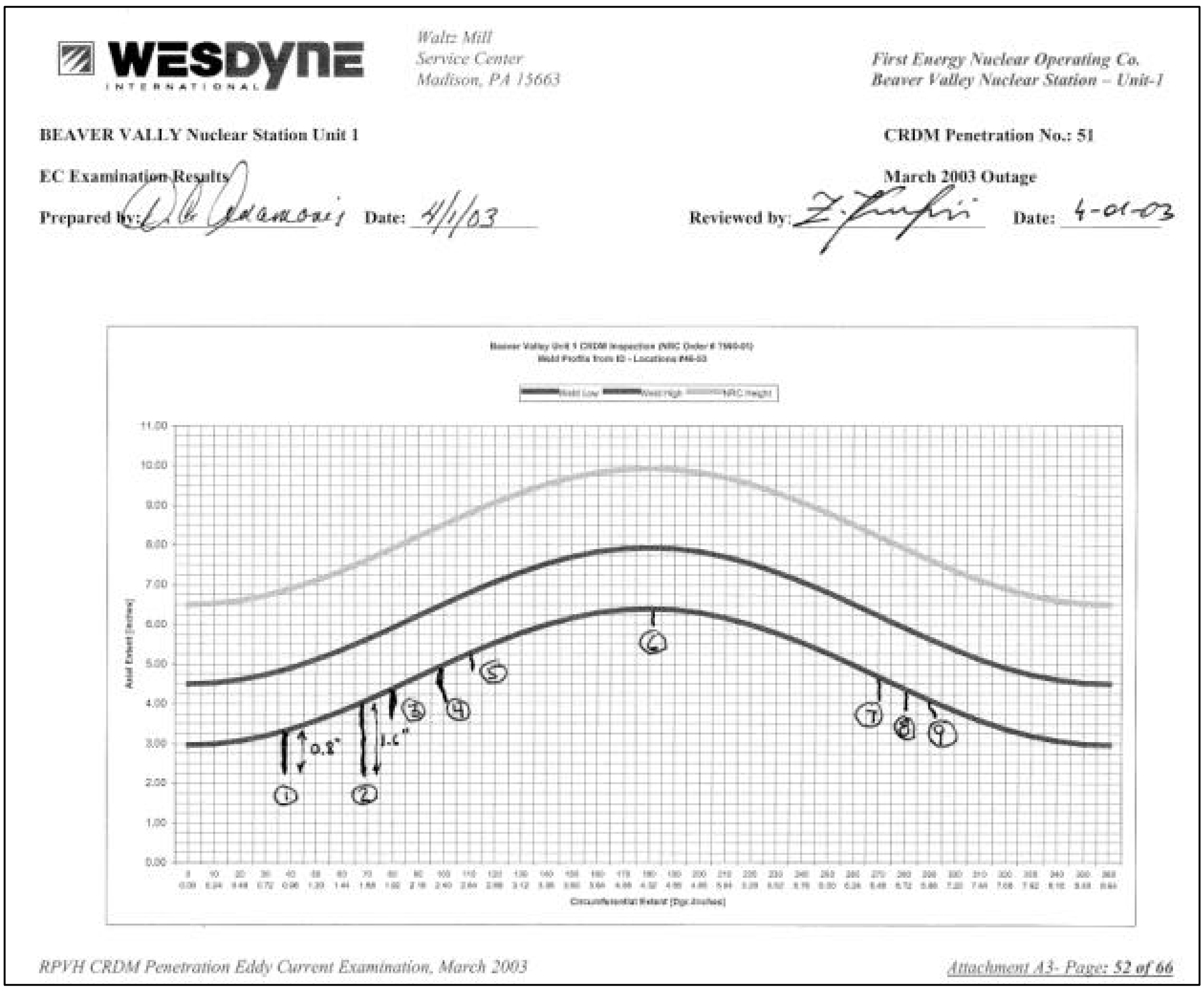


Figure 10: CRDM Penetration #51 Tube Profile

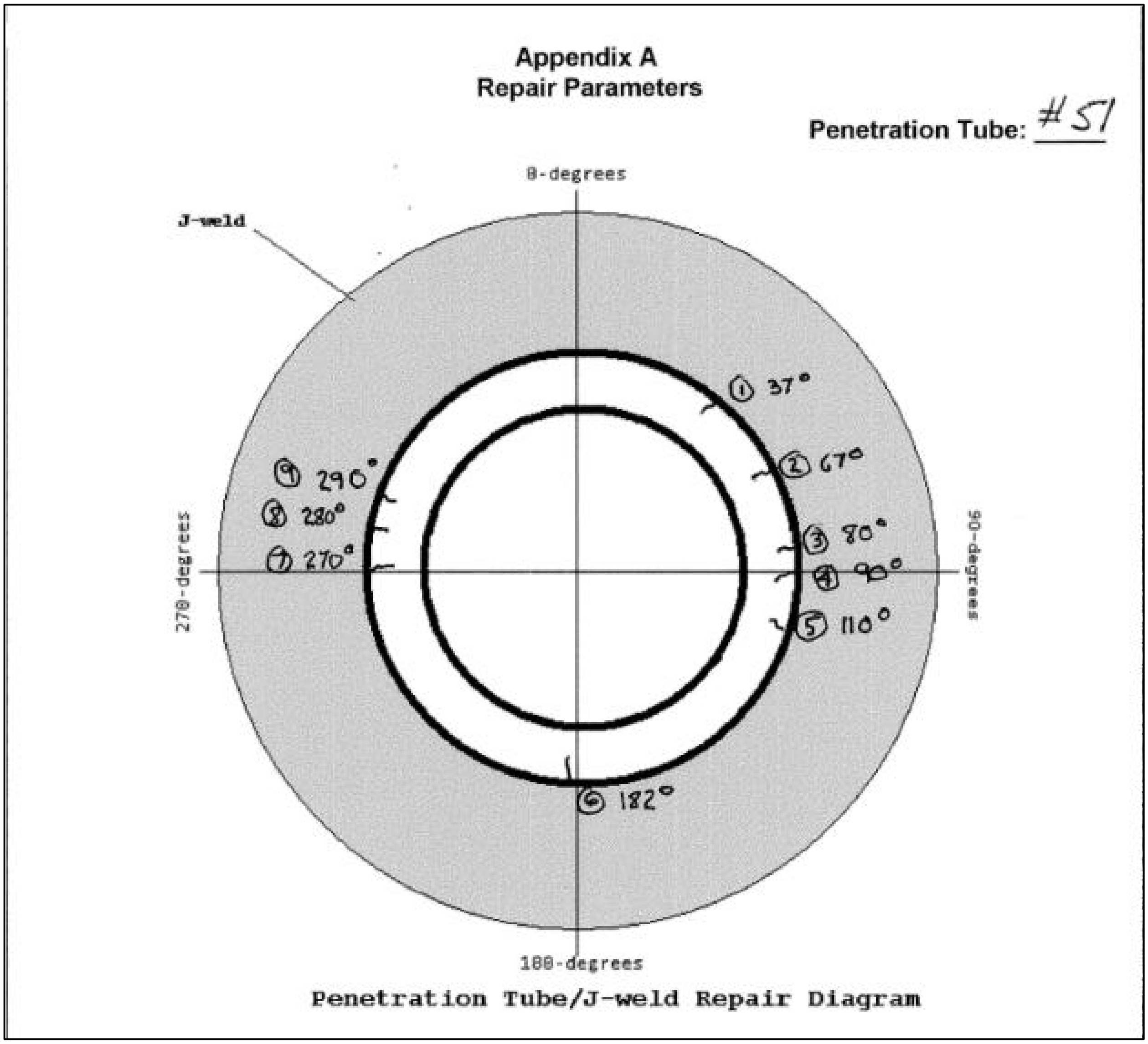


Figure 11: CRDM Penetration #51 Repair Parameters

Penetration #52: Flaw Characterization

Table 3: Penetration #52 Flaw Characterization

#	Length (Inches)	Depth (Inches)	Disposition	Circ. Location
1	0.3”	0.25”	Single Axial	75°
2	0.3”	0.20”	Single Axial	130°
3	0.3”	0.25”	Single Axial	225°
4	0.3”	0.20”	Single Axial	350°

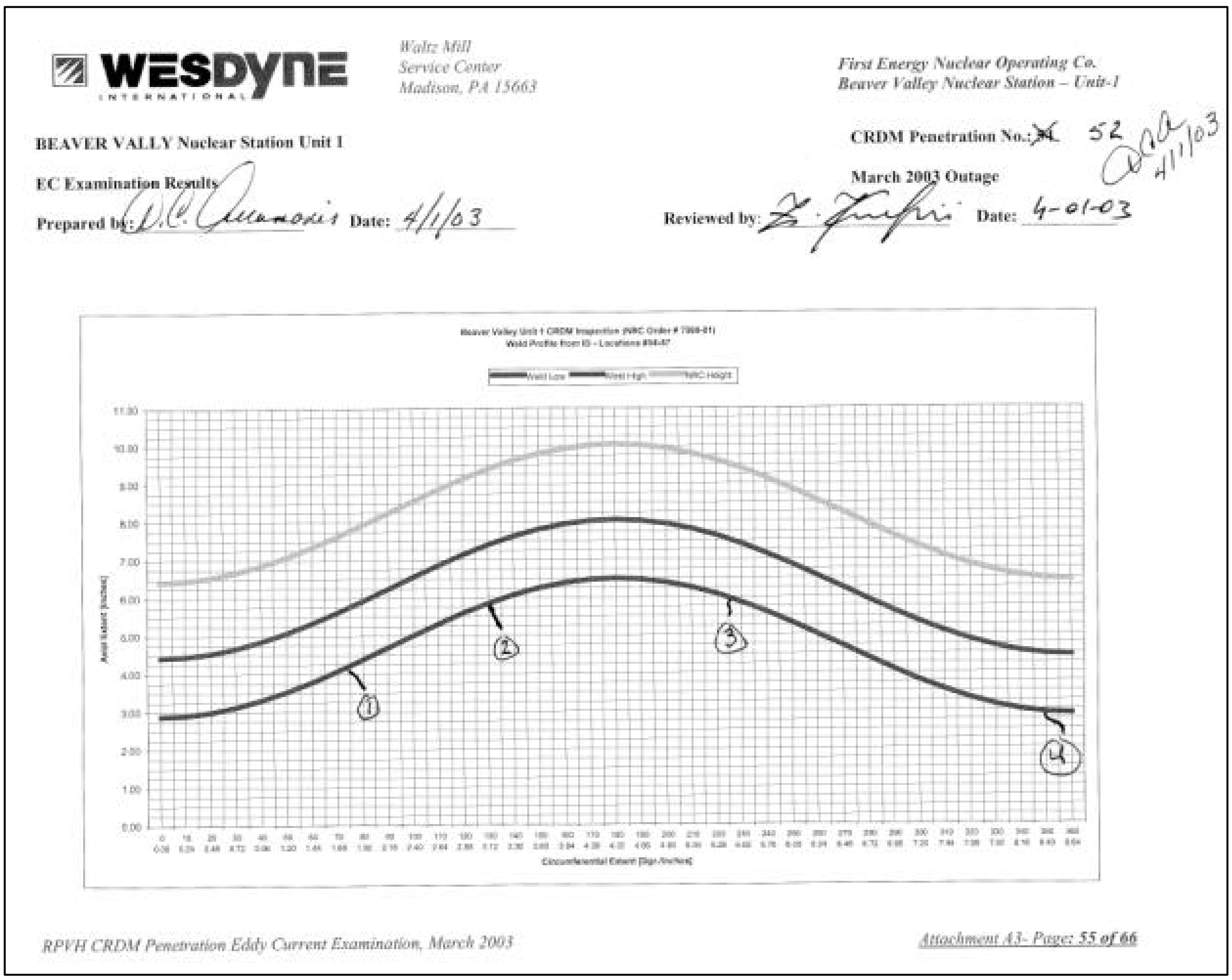


Figure 12: CRDM Penetration #52 Tube Profile

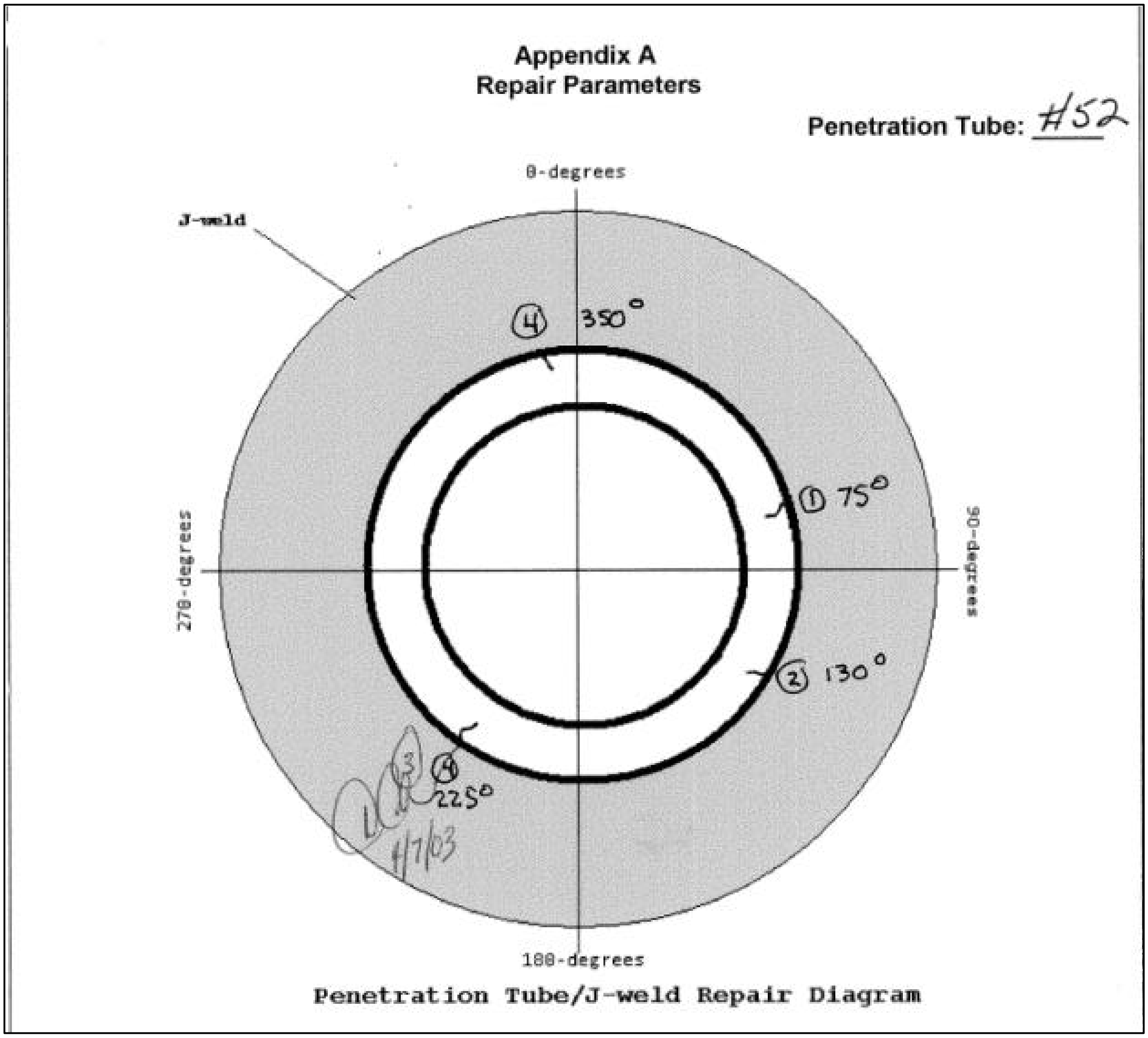


Figure 13: CRDM Penetration #52 Repair Parameters

Penetration #53: Flaw Characterization

Table 4: Penetration #53 Flaw Characterization

#	Length (Inches)	Depth (Inches)	Disposition	Circ. Location
1	0.3”	0.25”	Single Axial	42°
2	0.3”	0.20”	Single Axial	100°
3	0.3”	0.25”	Single Axial	215°
4	0.4”	0.15”	Multiple Shallow Axial	355°

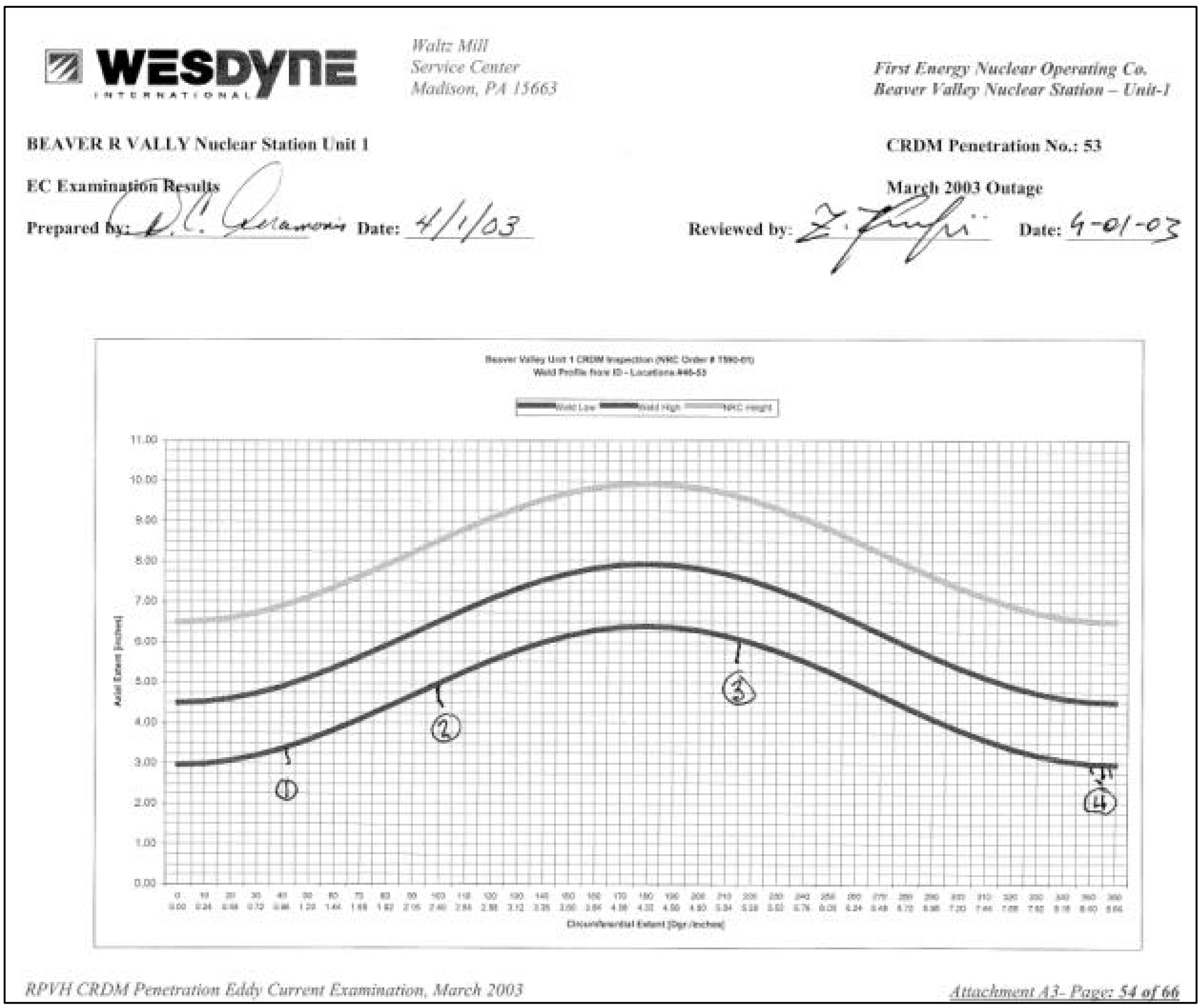


Figure 14: CRDM Penetration #53 Tube Profile

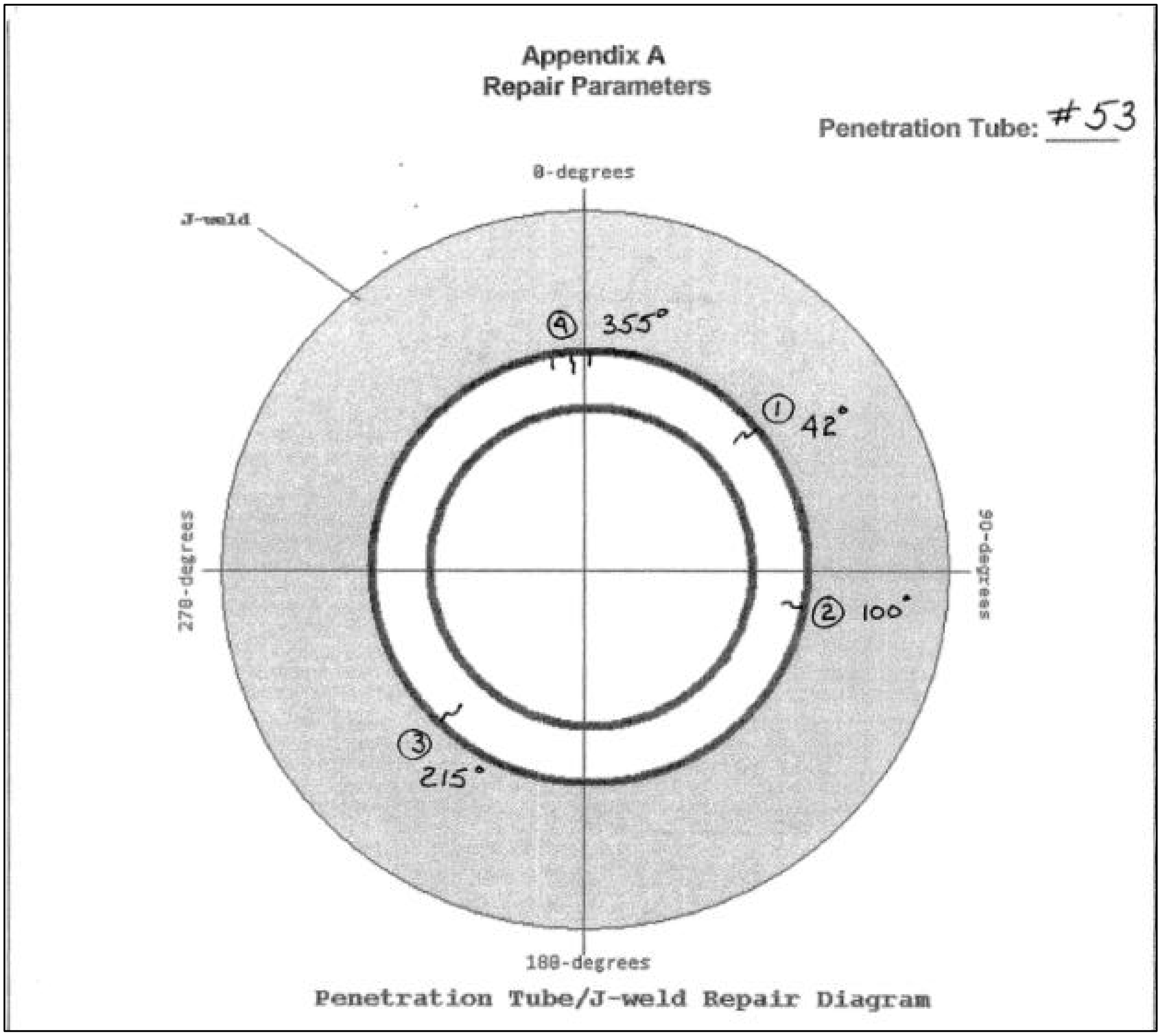


Figure 15: CRDM Penetration #53 Repair Parameters